Method for Development of Probabilistic Emission Inventories: Example Case Study for Utility NO_x Emissions

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Objectives

- Demonstrate a general probabilistic approach for quantification of variability and uncertainty in emission factors and emission inventories
- Demonstrate identification of key sources of uncertainty in an inventory in order to target future work to improve the inventory
- Develop a prototype software tool for calculation of variability and uncertainty in statewide inventories for a selected emission source and pollutant

Introduction

- Emission Inventories (EIs) are a vital component of environmental decision making.
- Characterize and evaluate the quality of emission inventories.
- Quantitative approach to characterizing both variability and uncertainty.
- Case study of NO_x emissions from electric utility power plants.
- A prototype software tool was developed to convey the example.

General Methodological Approach

- Compilation and evaluation of database
- Visualization of data by developing empirical cumulative distribution functions
- Fitting, evaluation, and selection of alternative parametric probability distribution models
- Characterization of uncertainty in the distributions for variability
- Propagation of uncertainty and variability in activity and emissions factors to estimate uncertainty in total emissions
- Calculation of importance of uncertainty

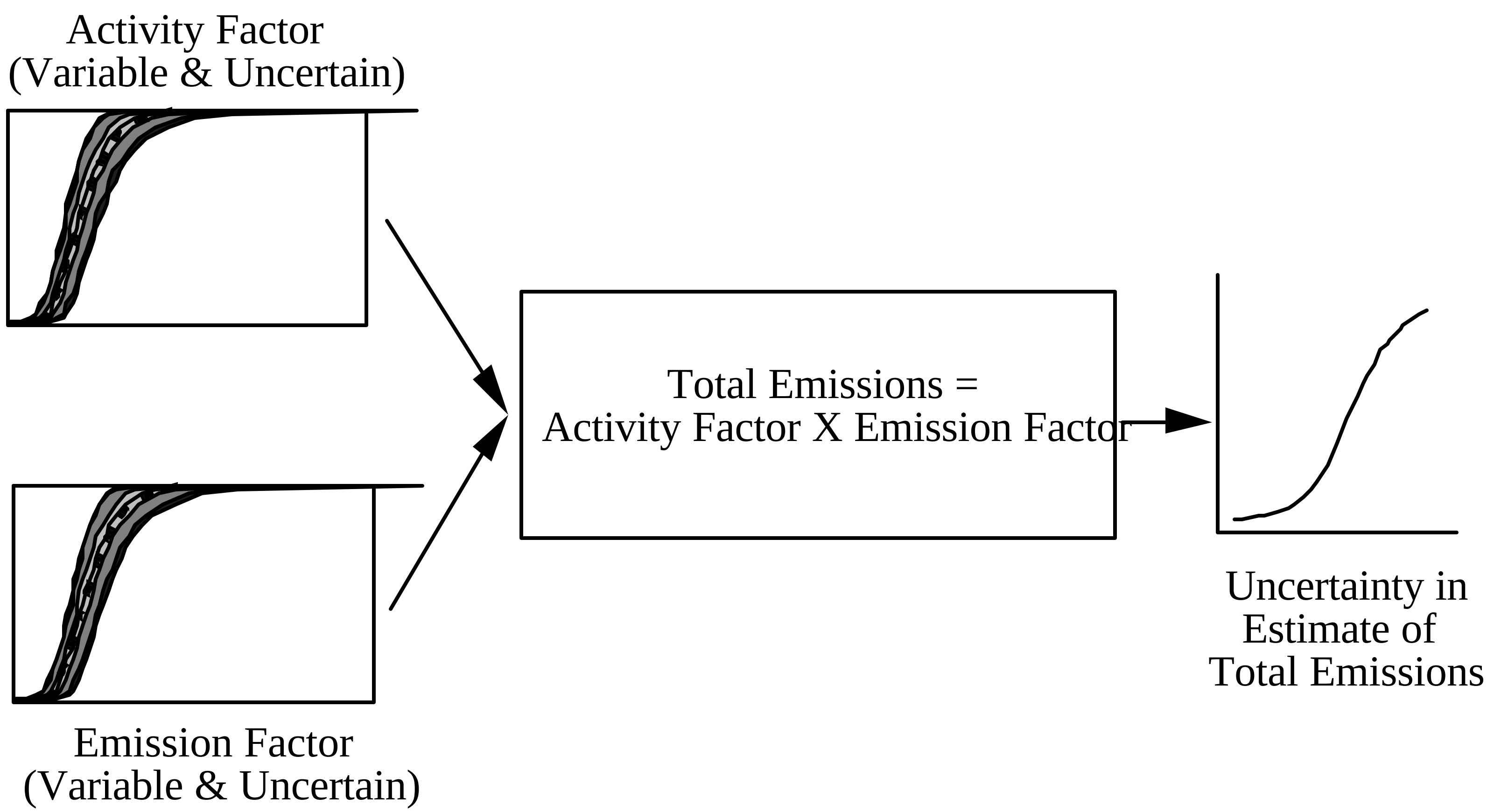
Compilation and Evaluation of Database

- Preliminary Summary Emissions Reports
  - Acid Rain Program of the U.S. EPA (http://www.epa.gov/acidrain/etsdata.html)
  - Quarterly Values Report
- Data Combination (Multiple Quarters)
- Data Screening
- Calculation of Emission Factors and Activity Factors for 6-month and 12-month averages
- Setup of the Internal Database for the prototype software tool

Fitting, Evaluation and Selection of Probability Distribution Models

- Distribution types
  - Normal
  - Gamma
  - Beta
  - Lognormal
  - Weibull
- Parameter estimation methods
  - Method of Matching Moments (MoMM)
  - Maximum Likelihood Estimation (MLE)
- Evaluation of goodness of fit
  - Statistical tests
  - Subjective judgment by visualization of data and fit
- Bootstrap simulation used to quantify uncertainty

Probabilistic Emission Inventories



Emission Inventory Model

- Emission Inventory Model based on electric utility power plants:

$$E = EF \bullet HR \bullet CP \bullet C$$

Where:

E = emissions (e.g., lb of NO_x as NO_2)
EF = emission factor (e.g., lb of NO_x as NO_2 per ton of coal burned)
HR = heat rate (BTU/kWh)
CP = capacity factor
C = capacity load (MW)

Identification of Key Sources of Uncertainty

- Importance of Uncertainty
  - Multi-linear Regression
  - Correlation Coefficient
  - Probabilistic Sensitivity Analysis
- Correlation coefficient was chose in the prototype software tool

$$U_\rho = \frac{\sum_{k=1}^{m}(x_k - \bar{x})(y_k - \bar{y})}{\sqrt{\sum_{k=1}^{m}(x_k - \bar{x})^2 \times \sum_{k=1}^{m}(y_k - \bar{y})^2}}$$

U_p : Importance of uncertainty from model input y samples

x_k : Model output samples

$\bar{x}$: The mean of x_k samples

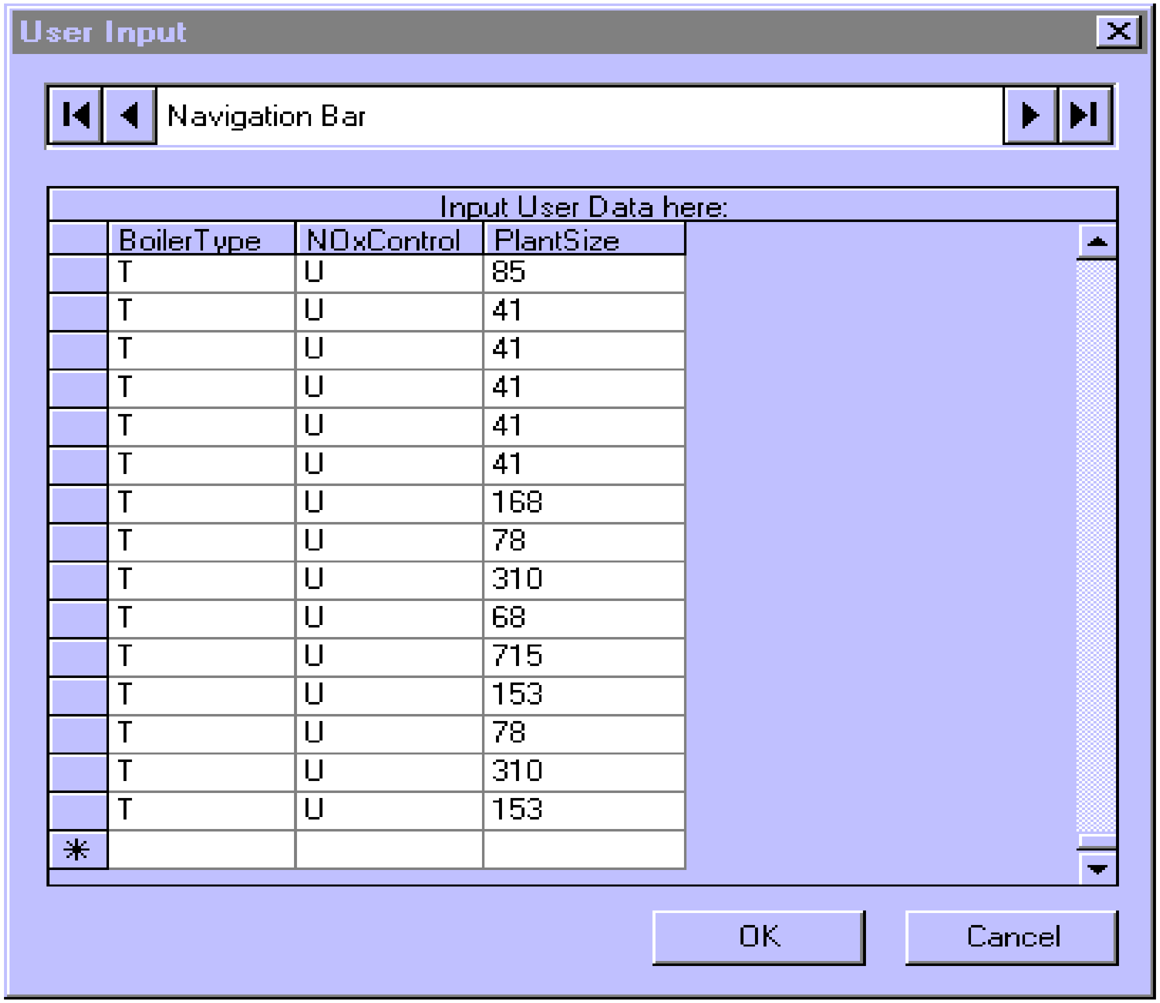
y_k : Model input samples

$\bar{y}$: The mean of y_k samples

Case Study

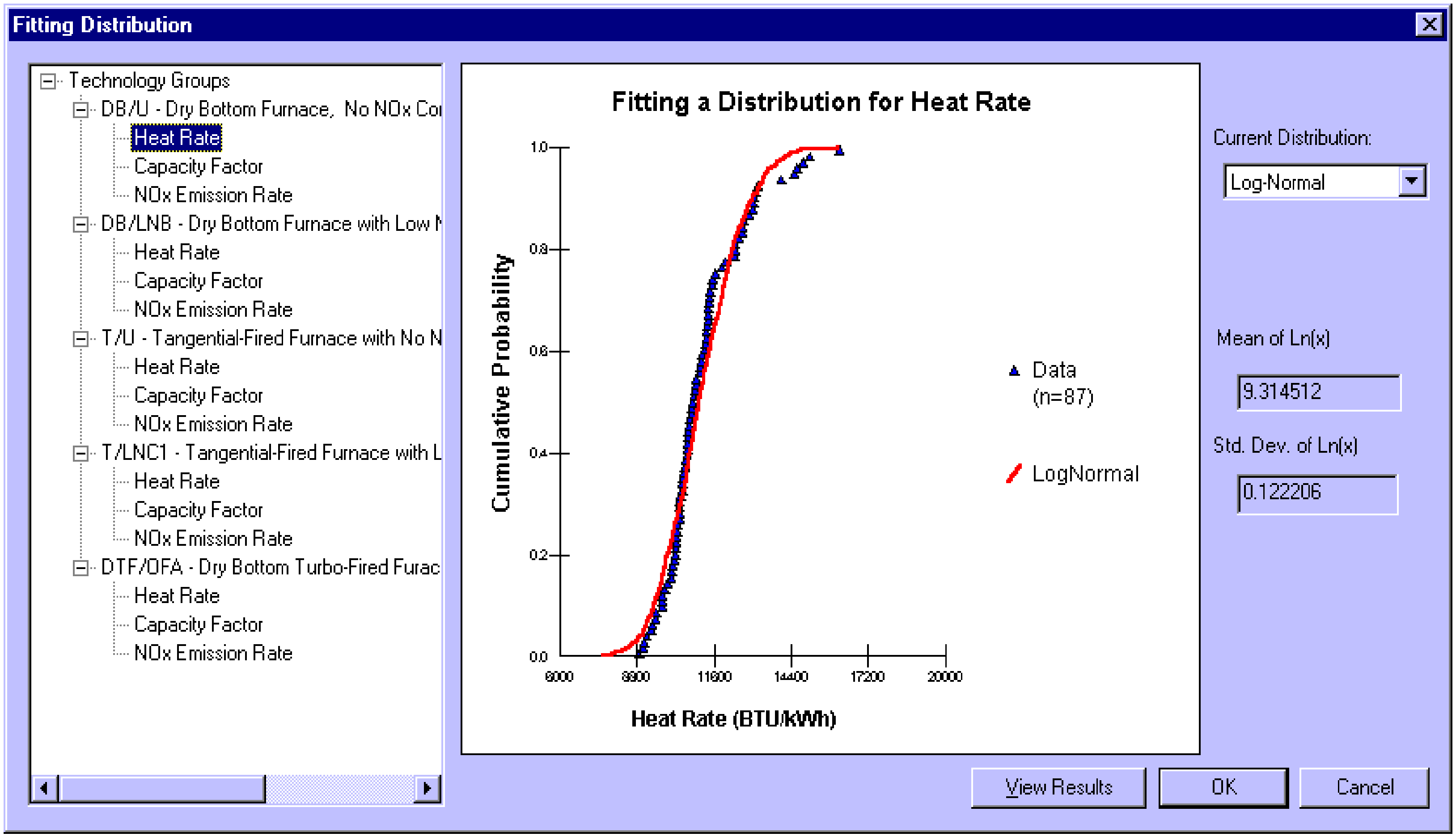
- Power Plant NO_x Emissions for Selected Power Plants in the State of North Carolina
    - •19 tangential-fired boilers with no NO_x controls (T/U)
    - •11 tangential-fired boilers using Low NOx Burners and overfire air option 1(T/LNC1)
    - •12 dry bottom wall-fired boilers with no NO_x controls (DB/U)
    - •3 dry bottom wall-fired boilers using low NO_x burners (DB/LNB)
- Case study was done using a prototype software tool based on a 6-month average database

User Input: Boiler Type, NO_x Control Option, and Size of Each Unit



BoilerType	NOxControl	PlantSize
T	U	85
T	U	41
T	U	41
T	U	41
T	U	41
T	U	41
T	U	168
T	U	78
T	U	310
T	U	68
T	U	715
T	U	153
T	U	78
T	U	310
T	U	153

Fitting, Evaluation and Selection of Probability Distribution Models



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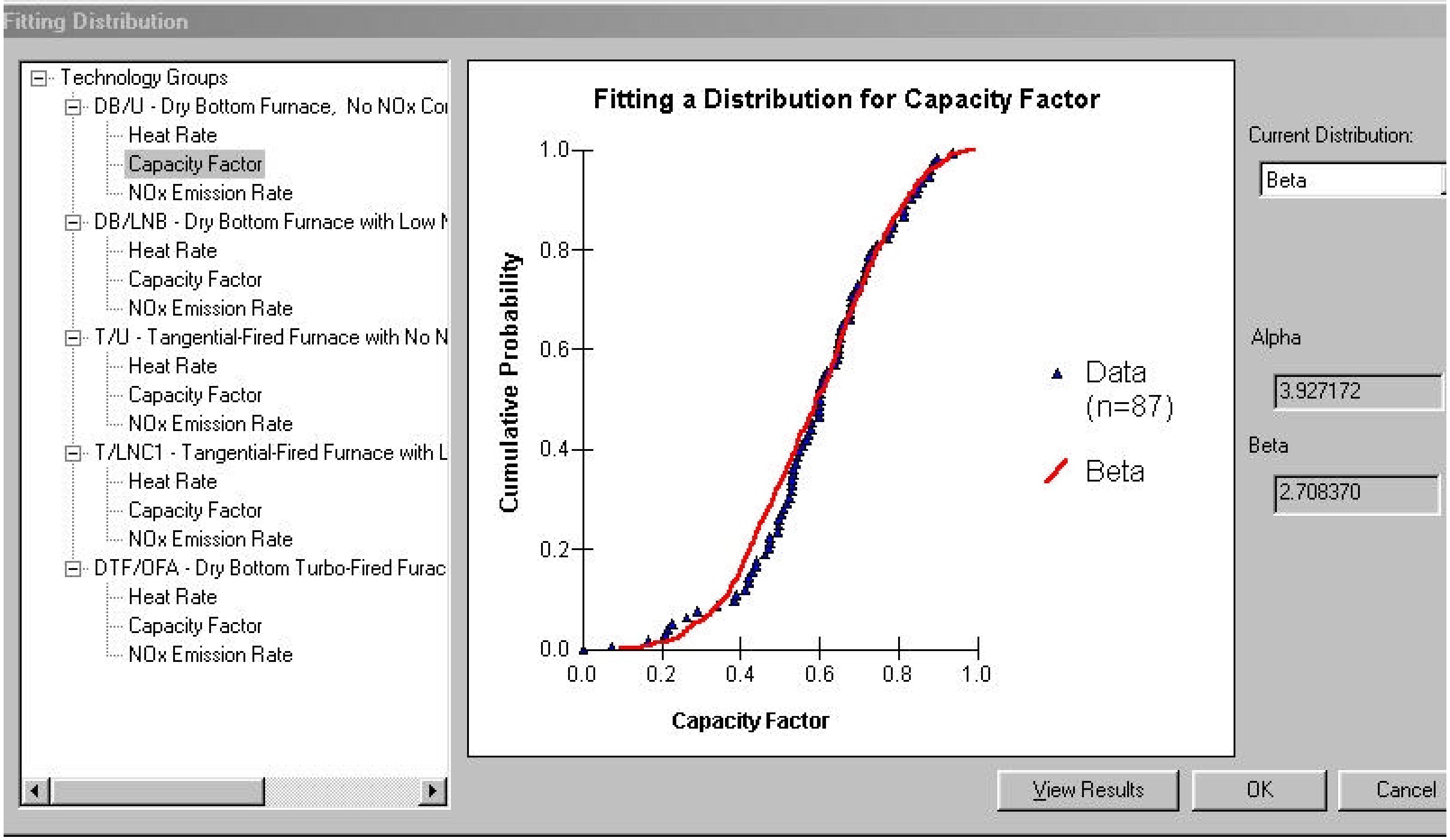

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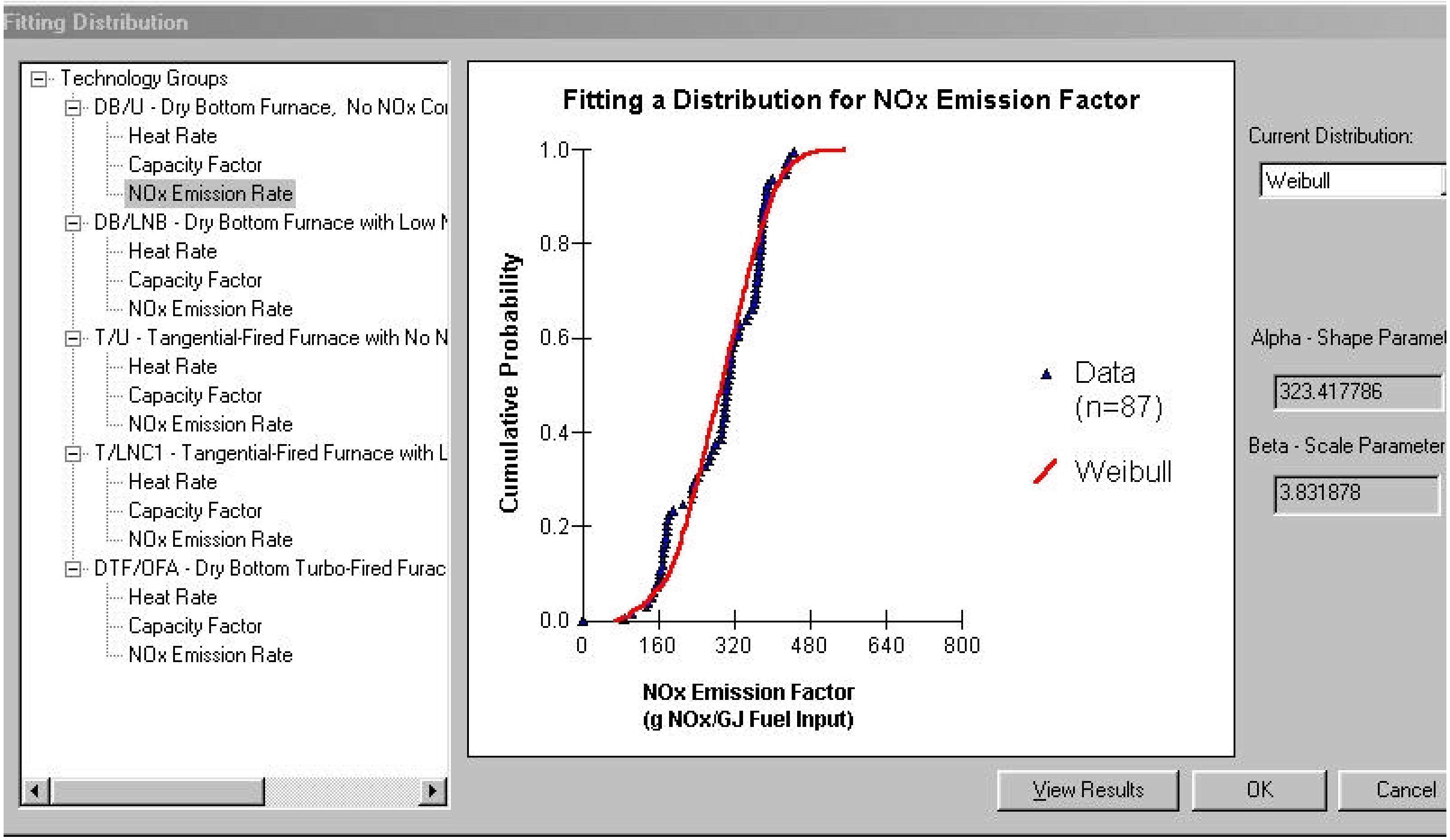
Fitting, Evaluation and Selection of Probability Distribution Models



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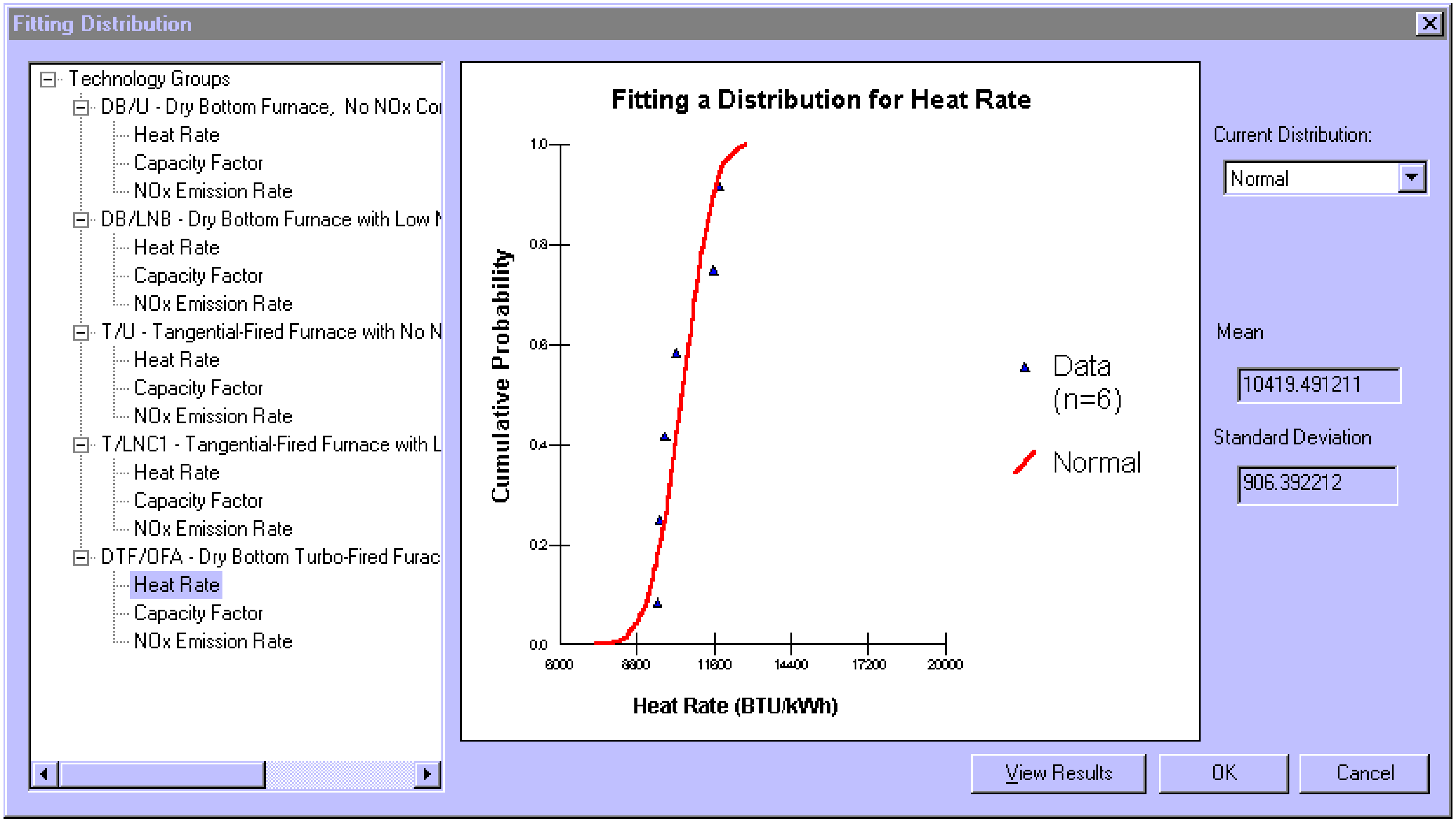

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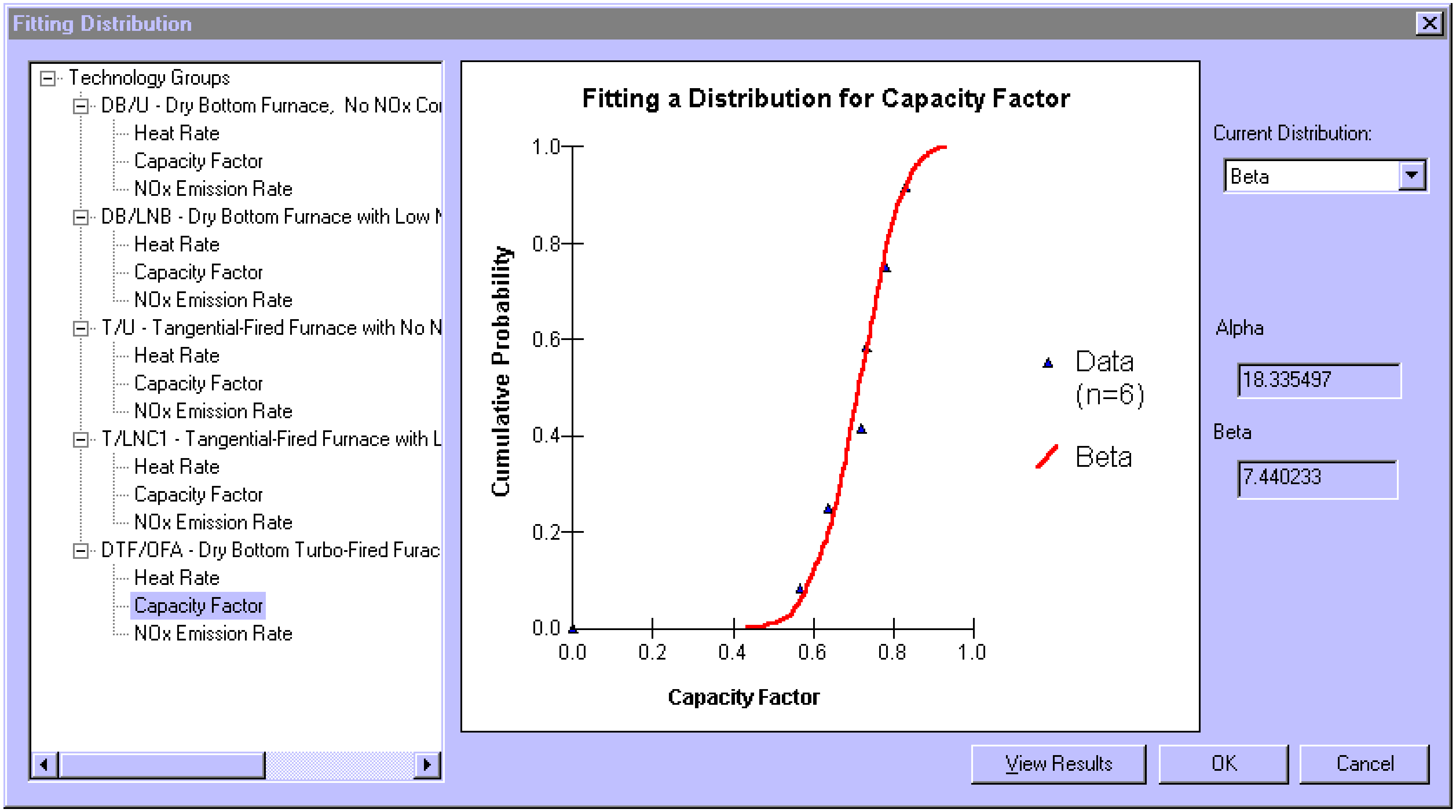

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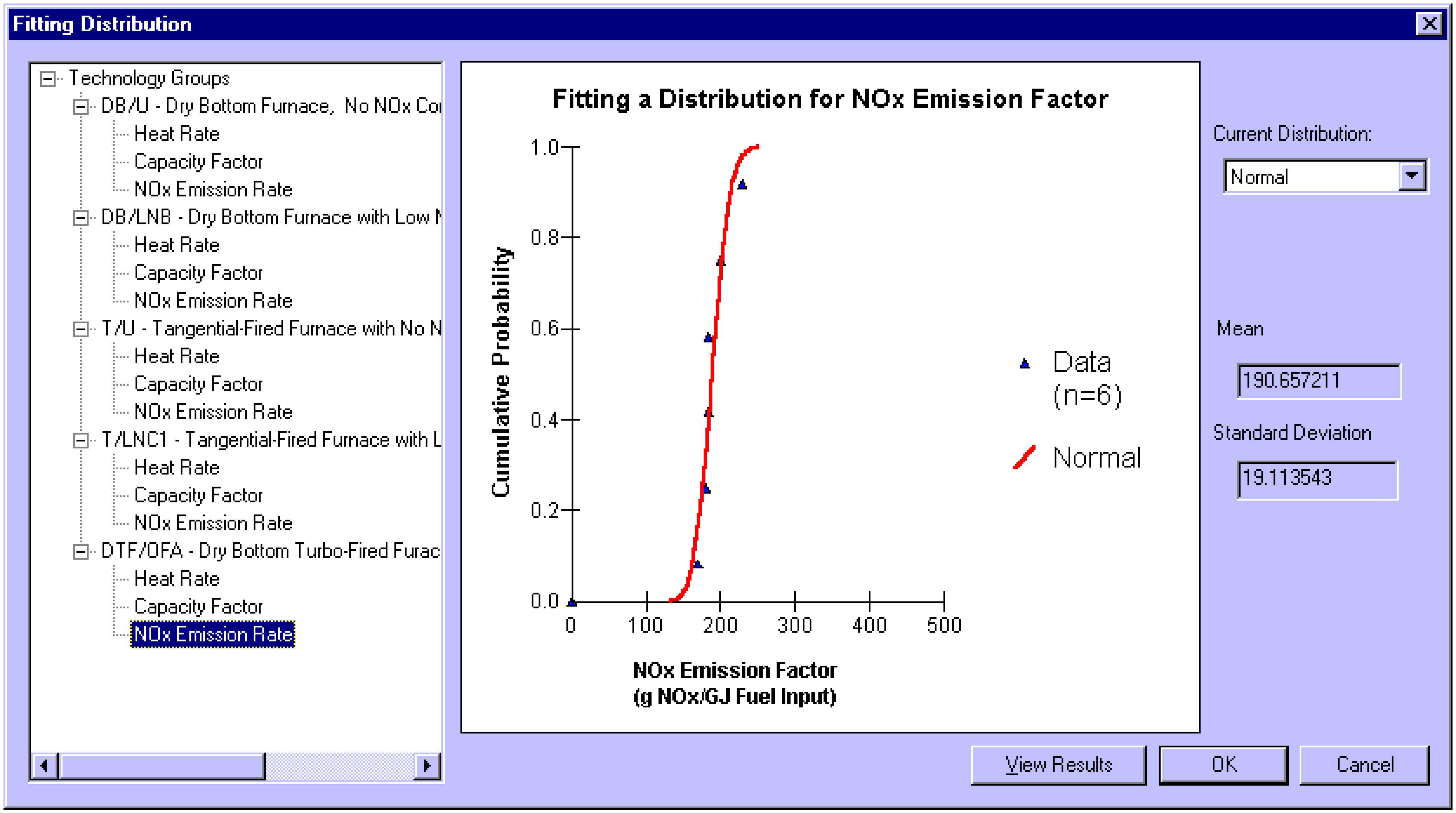

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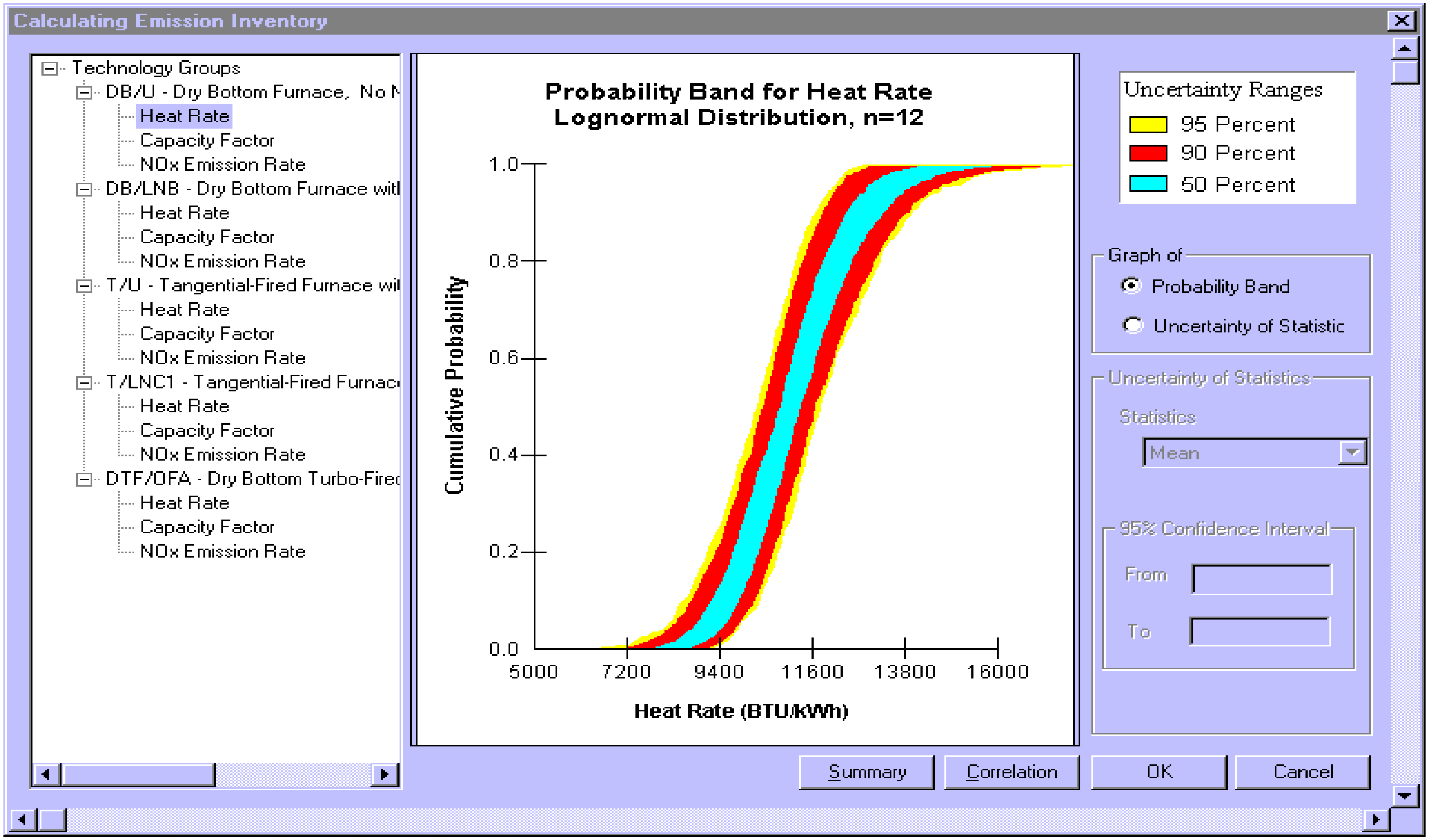
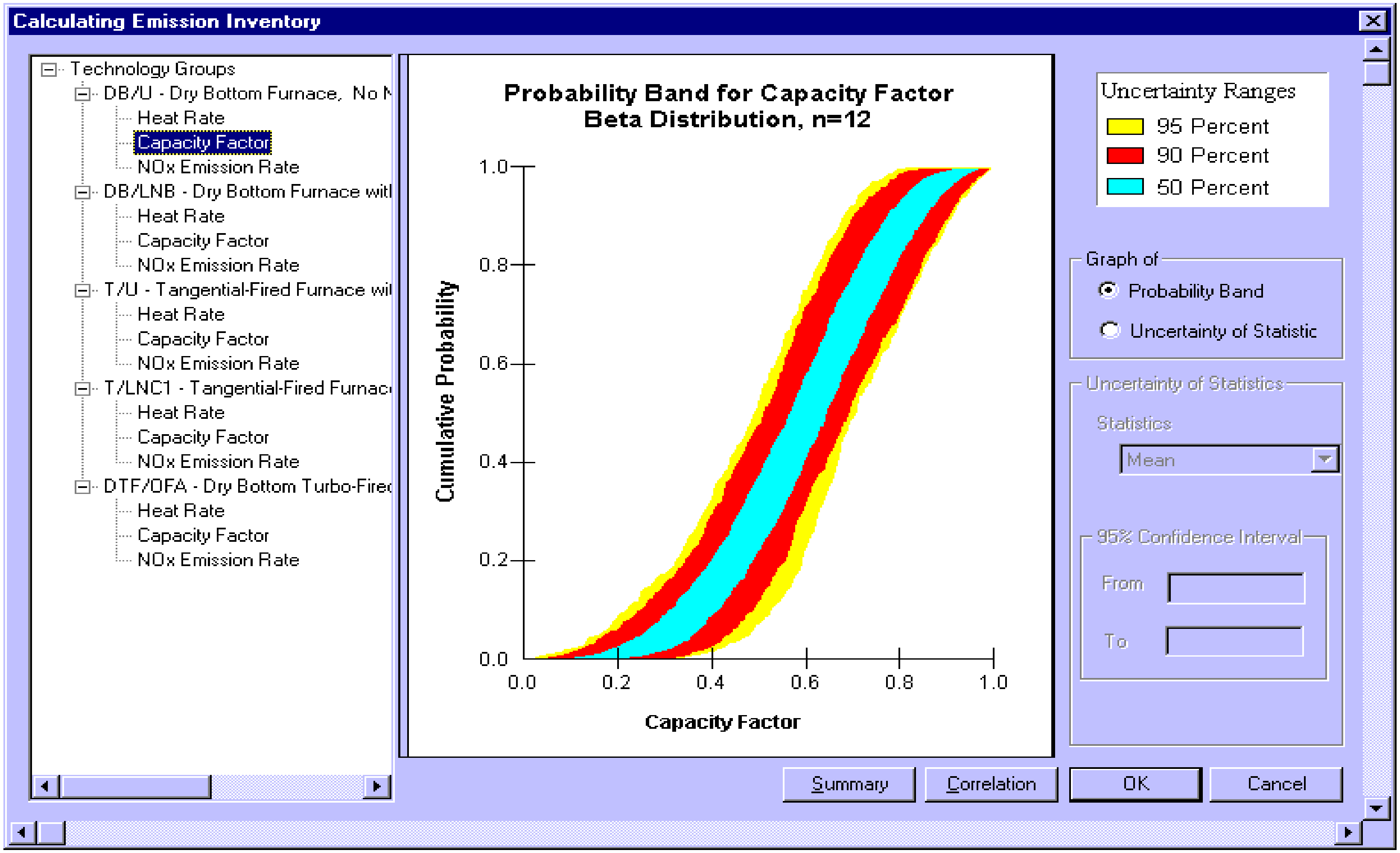
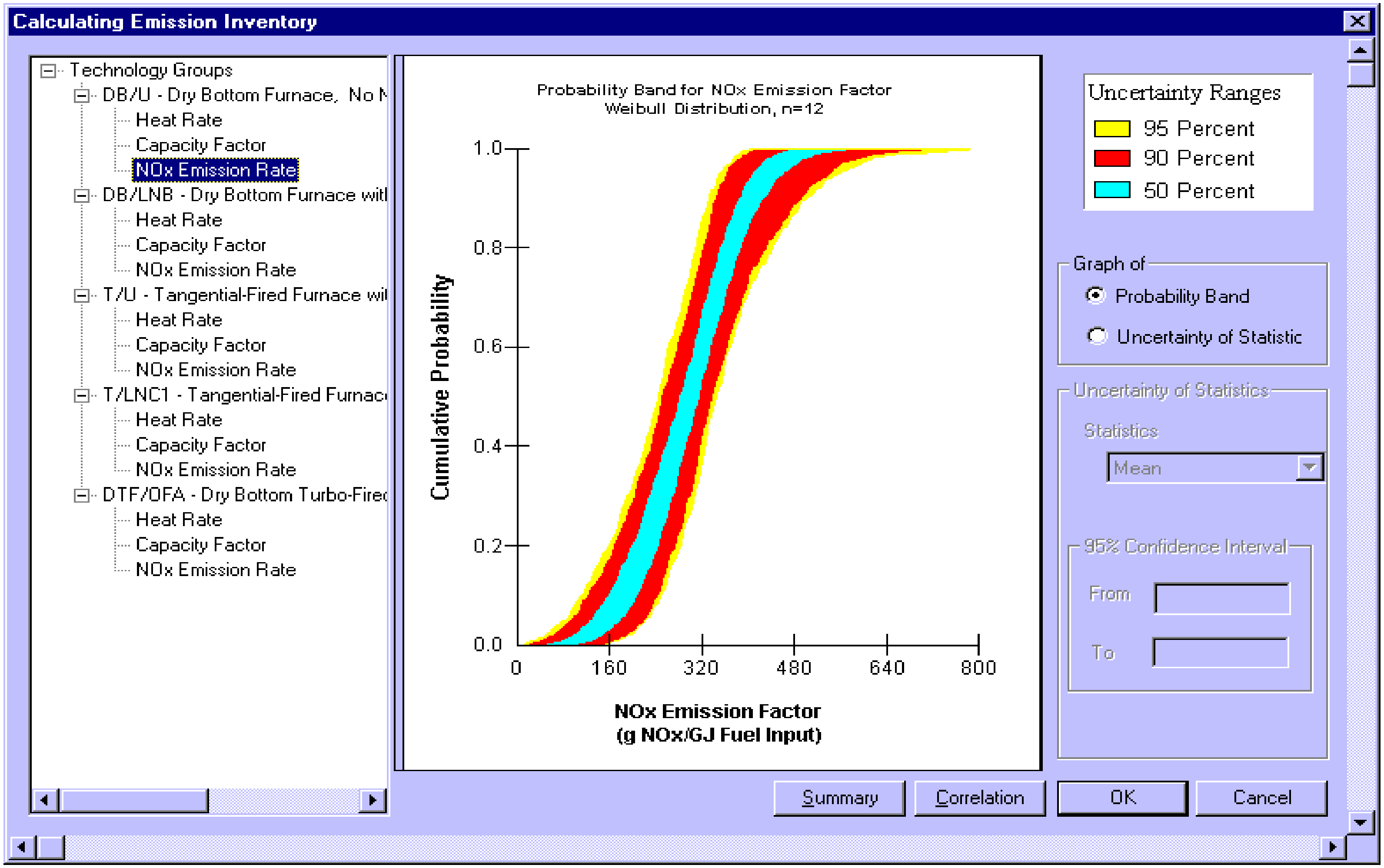
Characterization of Variability and Uncertainty in Heat Rate: An Example



Characterization of Variability and Uncertainty in Capacity Factor: An Example



Characterization of Variability and Uncertainty in NO_x Emission Factors



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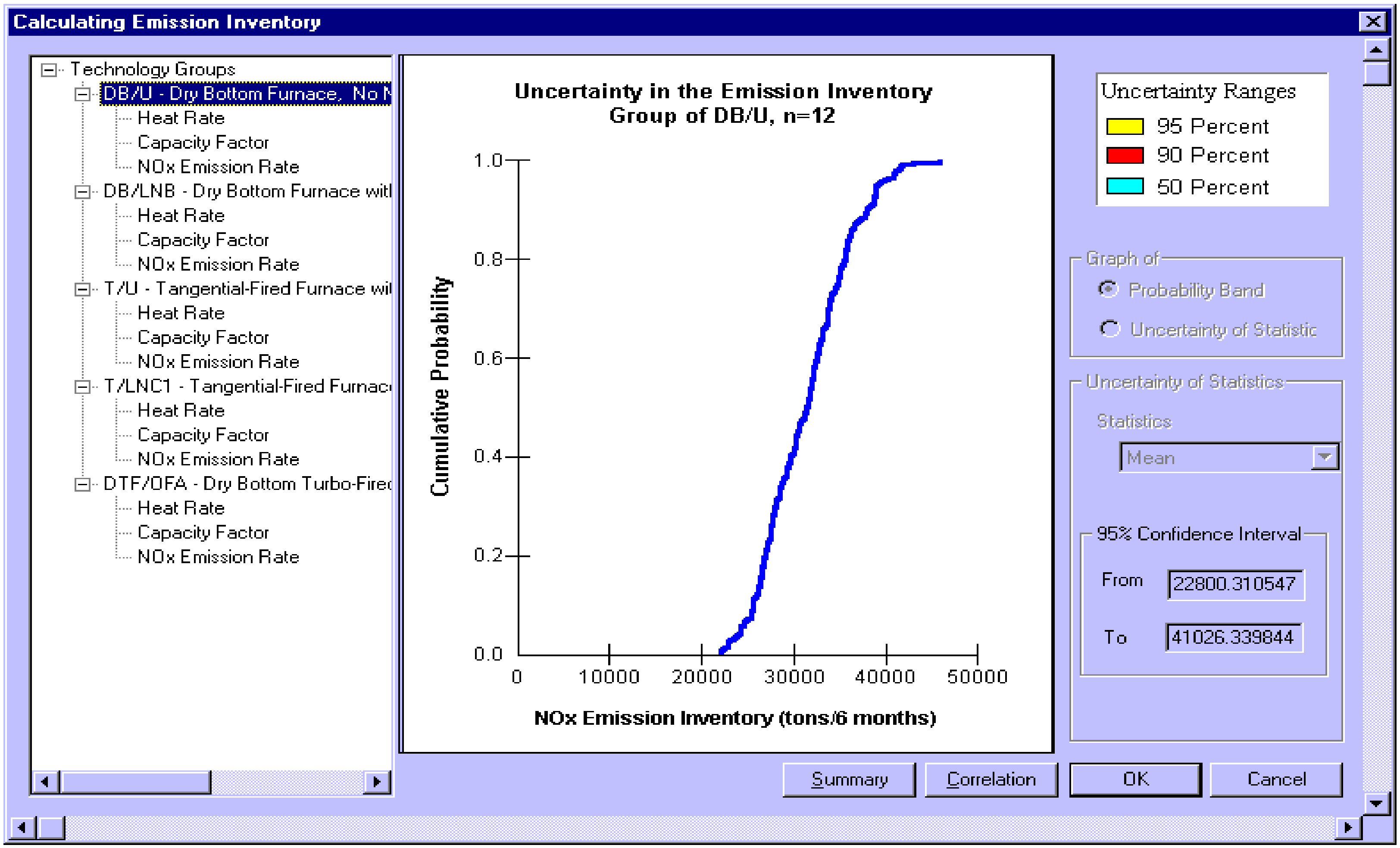
Uncertainty in Emission Inventory for Dry-Bottom Boilers with No NO_x Control



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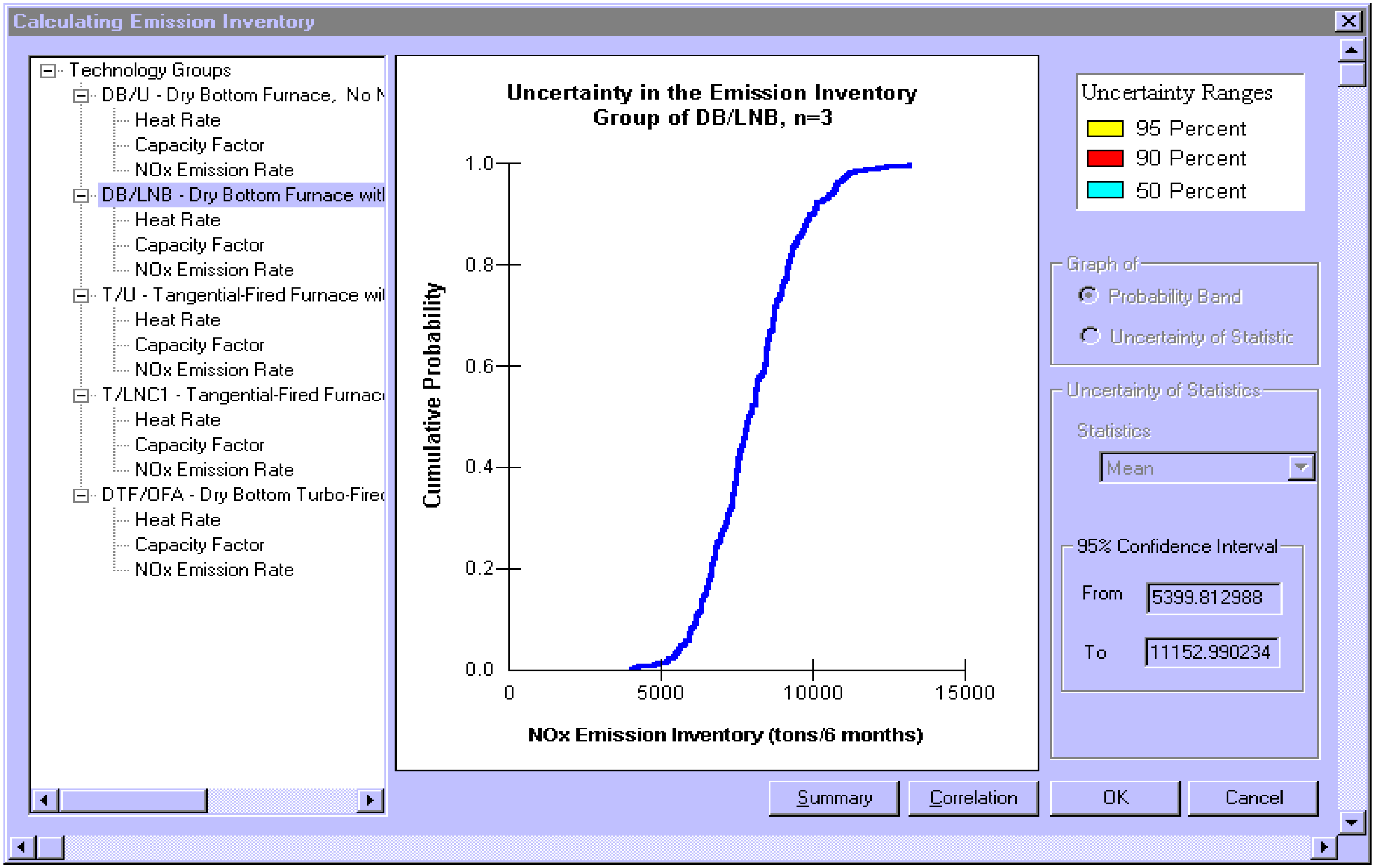

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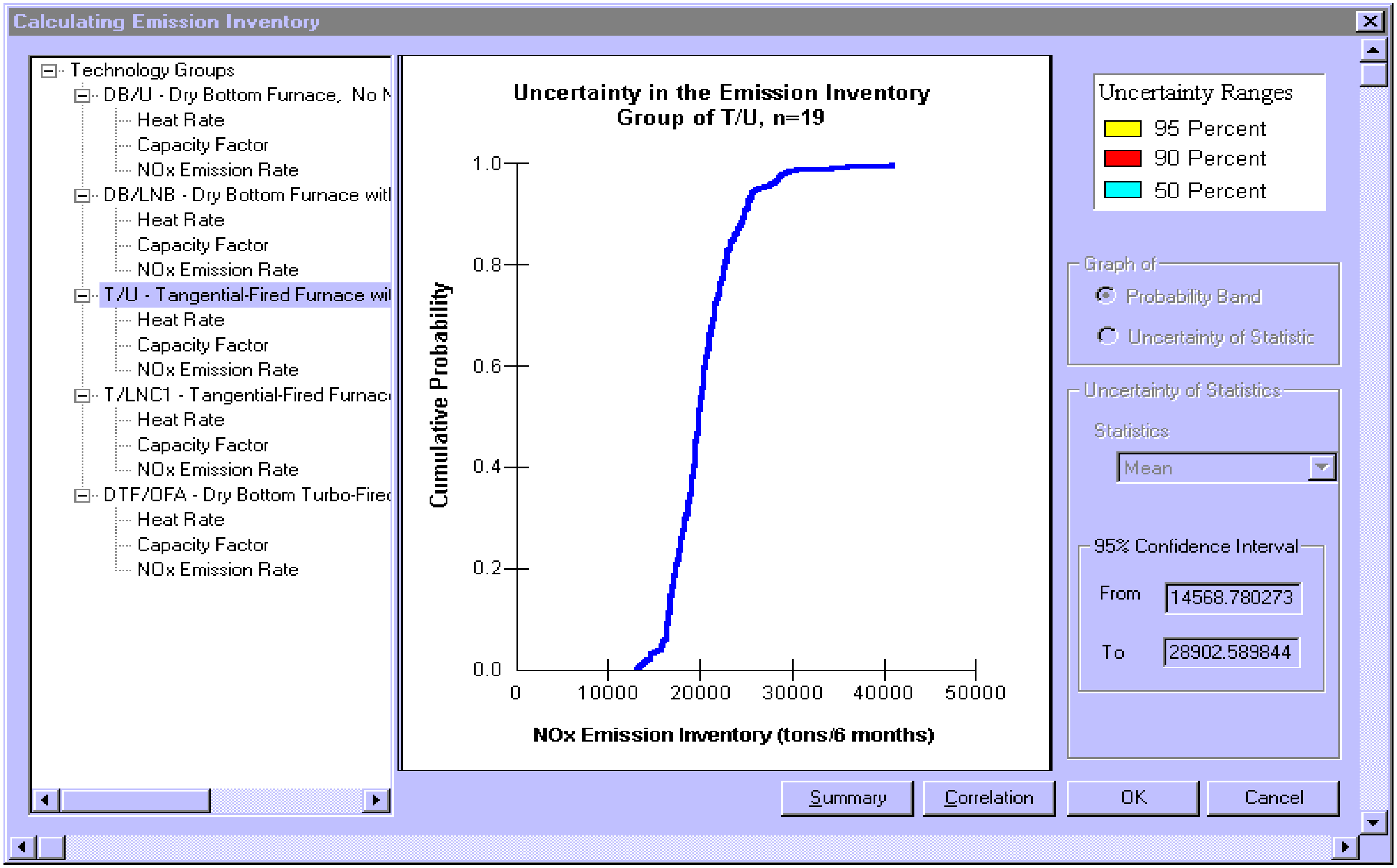
Uncertainty in Emission Inventory for Tangential Boilers with No NO_x Control



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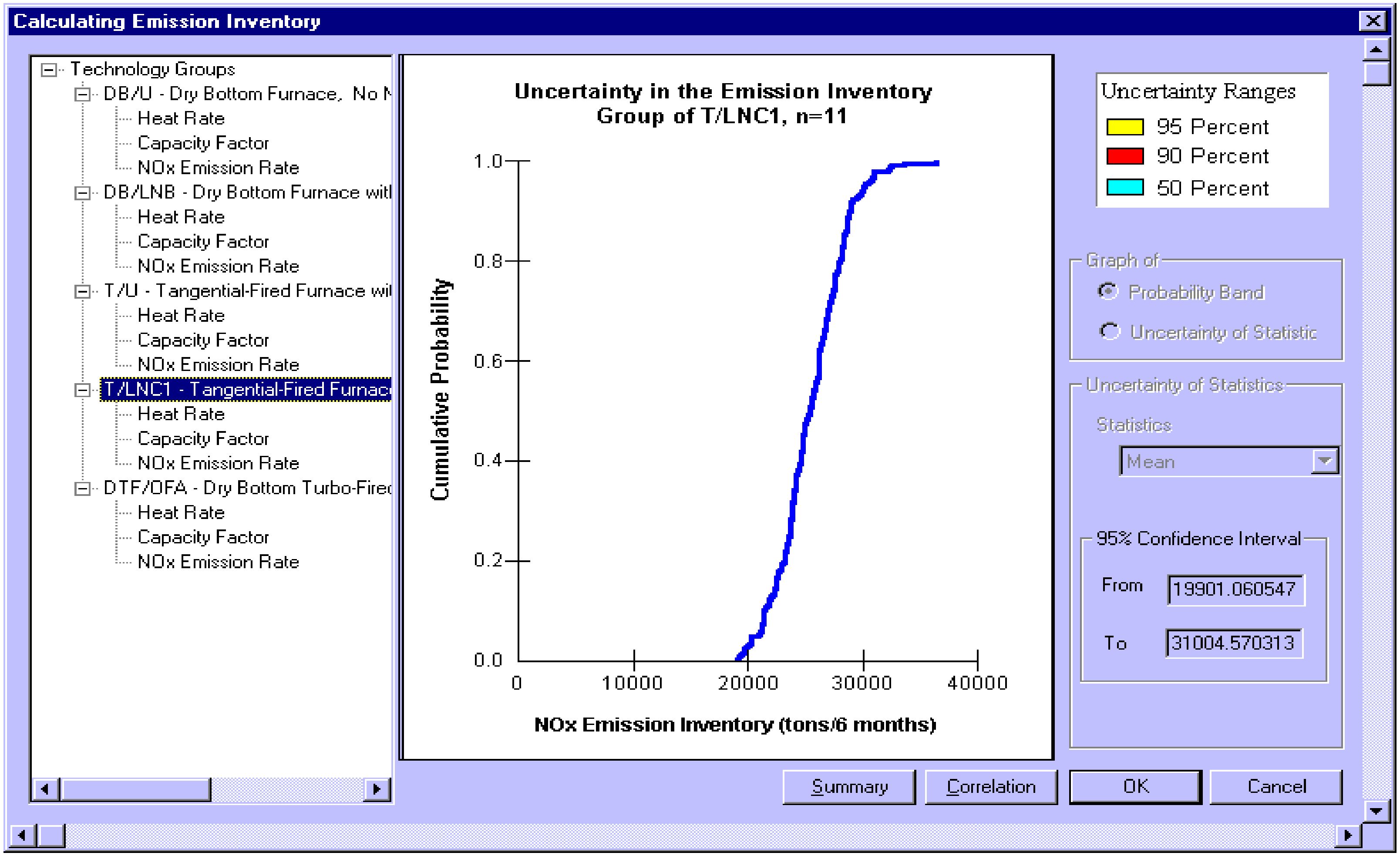
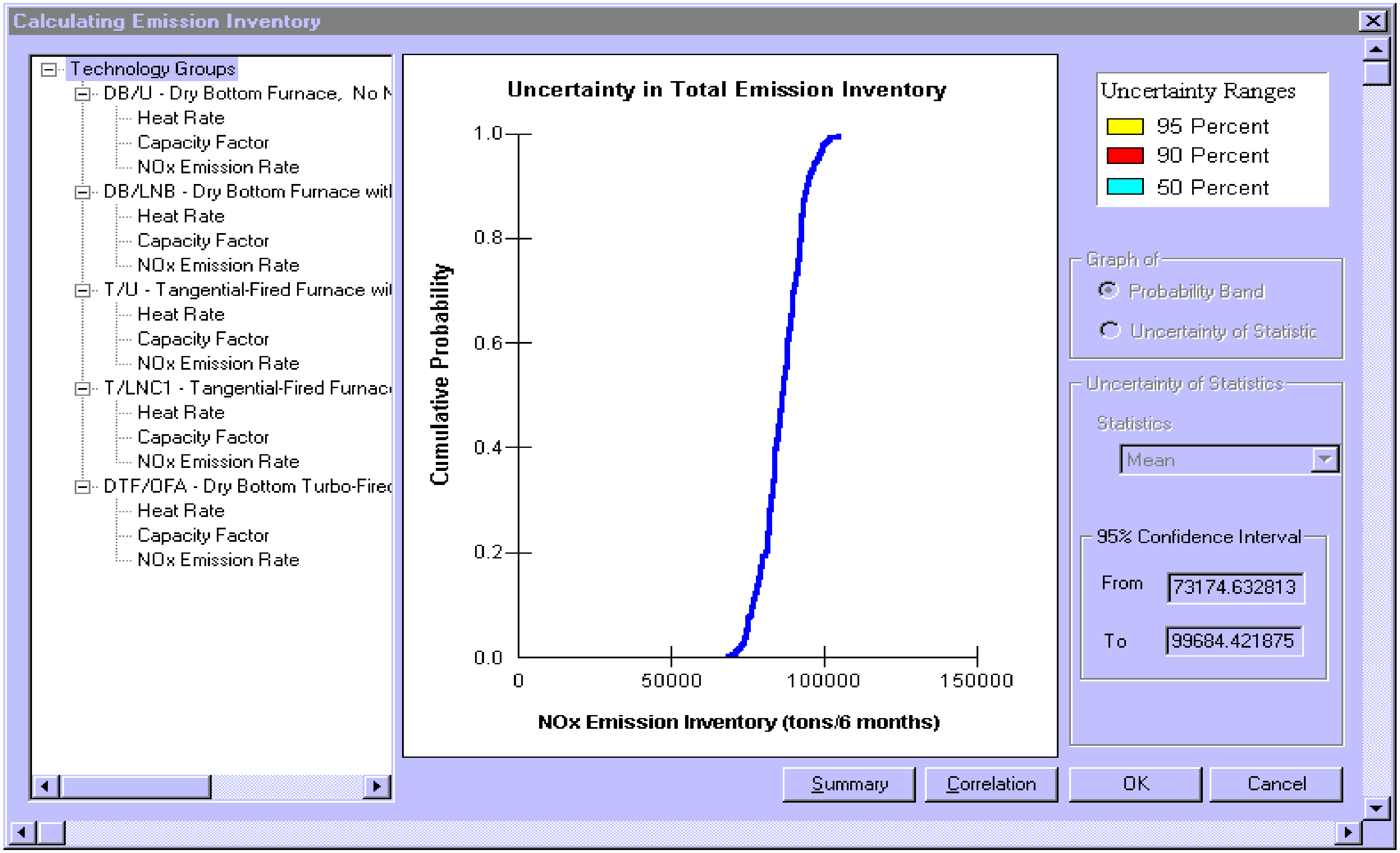
Uncertainty in Emission Inventory for Tangential Boilers with NO_x Control



Uncertainty in Total Emission Inventory

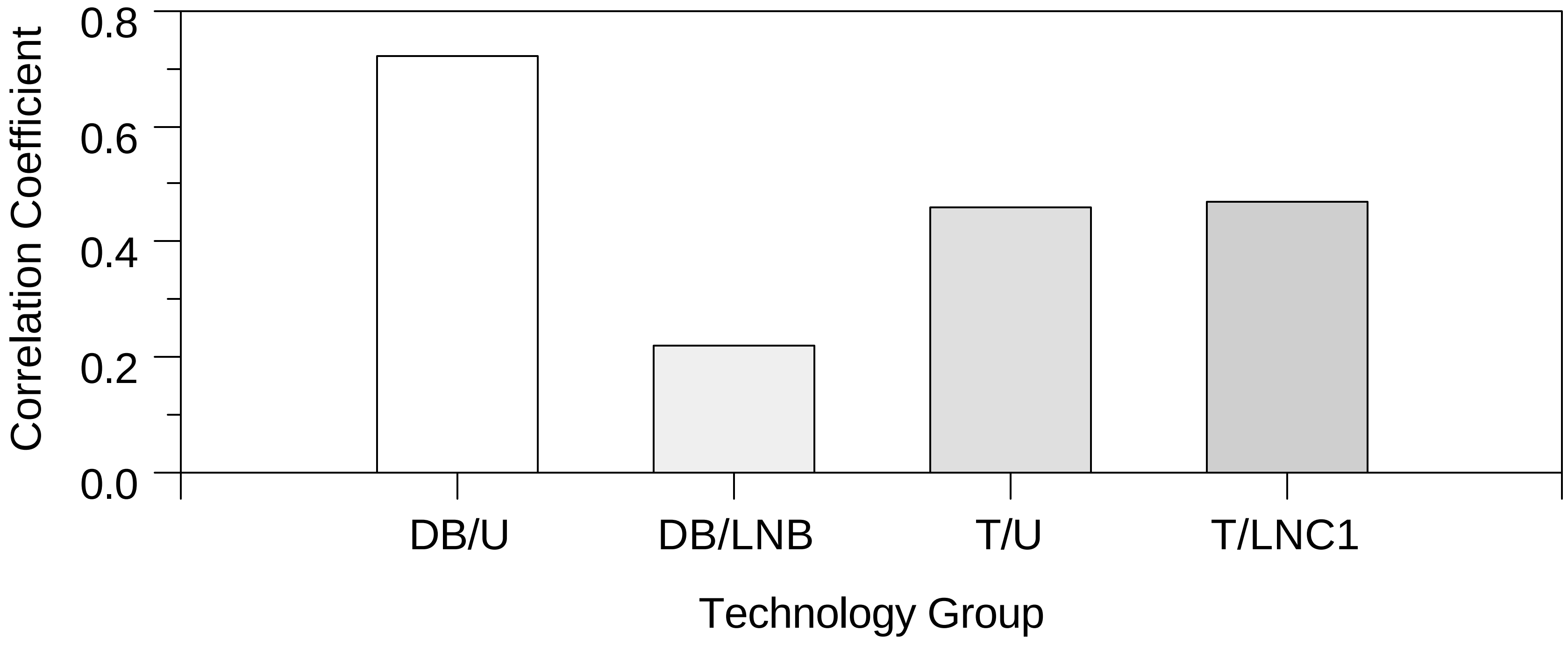


Summary of Probabilistic Emission Inventory

Technology Group	2.5th Percent	Mean	97.5th Percentile	Random Error (%)[a]	
				Negative	Positive
DB/U	21,700	31,100	40,100	-30	+29
DB/LNB	5,600	8,100	11,400	-31	+39
T/U	15,300	20,400	28,600	-25	+40
T/LNC1	19,800	25,200	31,100	-21	+23
Total	71,800	84,800	99,900	-15	+18

[a] Results shown are the relative uncertainty ranges for a 95 percent probability range, given with respect to the mean value.

Identification of Key Sources of Uncertainty



Conclusion

- Demonstrated a general methodological approach for quantifying variability and uncertainty in air pollutant emission inventories
- Developed a prototype software tool to implement the methodology
- Visualization of emission and activity factor databases
- Identification of key sources of uncertainty to help analysts improve the quality of the inventory
- Quantification of uncertainty in 6-month emissions
  - Quality of emission inventory estimates
  - Likelihood of meeting emissions budgets
  - Other decision implications (e.g., trends, air quality modeling)

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- For more information:

  http://www4.ncsu.edu/~frey/